“WLAN Prestta™ antennas for implementation in gateways with MIMO technology”

Carmen Redondo MSc. EE
Antenna Engineer at Ethertronics

***Abstract* — This paper presents a low-cost MIMO antenna solution for gateways with embedded WLAN Prestta antennas. These antennas are designed using Ethertronics’ patented IMD (Isolated Magnetic Dipole™) technology, which provides high isolation and excellent performance for its small size. Ethertronics’ WLAN Prestta™ antennas are evaluated and they equal or improve the antenna performance and significantly reduce the volume employed compared to other vendors’ antennas. This solution also can be applied to other similar devices, such as routers and access points.**

I. INTRODUCTION

Nowadays MIMO (Multiple Input Multiple Output) techniques are widespread in wireless communications, especially in WLANs (Wireless Local Area Networks). MIMO techniques maximize the capacity of a communication system by overcoming the fading of signals due to multipath propagation in indoor and urban environments. MIMO requires several antennas in a trending smaller area, which makes it extremely challenging for antenna designers. Gateways, access points and routers are frequently implemented with external sleeve dipole antennas and, with the new standard 802.11n that supports MIMO, it is common today to see three or four antennas in the same device.

This paper presents the WLAN Prestta antenna as a suitable solution for these devices. Ethertronics’ patented IMD technology provides high isolation and performance, what allows smaller antennas in a reduced area. In this paper we compare the performance and size of the often used external sleeve dipoles and other vendor’s embedded antennas with Ethertronics’ embedded Prestta antennas. In addition, we introduce a real product design for a commercial gateway where the Prestta antennas are implemented directly on the main PCB of the device.

II. MIMO SYSTEMS

Multipath propagation in indoor and urban environments produces undesired fading in the received signals, with potential for full signal cancellation. Therefore, MIMO techniques use several antennas to avoid this problem. These antennas can use spatial, polarization or pattern diversity depending on the different position, type of polarization or radiation pattern they have. These configurations are intended to reduce the correlation between antennas, caused mostly by the mutual coupling.

There are different MIMO techniques to avoid fading, such as equal gain combining, selection combining and maximum ratio combining. Selection combining, a very common technique, requires separate receivers in order to constantly be able to determine signal amplitude for all antennas at the same time. This technique always chooses the strongest signal from any of the antennas, reducing then the possibility of fading. This corresponds to an increased signal-to-noise ratio (SNR) in the fading dips and often an increase in the channel capacity.

Correlation, diversity gain and MIMO capacity can easily be measured in a reverberation chamber, which we use for the diversity measurements in this paper. It is a metal cavity that supports several resonant modes which are perturbed by stirring methods inside the chamber and creates a fading environment.

Figure 1 shows the cumulative probability distribution function (CDF) of the measured signal powers inside a reverberation chamber between two parallel dipoles with 15 mm spacing [1]. The Rayleigh distribution curve is the theoretical simulation of a multipath environment. The curve of the ideal reference antenna follows the theoretical Rayleigh distribution very closely, which is the guarantee of a scattering environment. Each antenna (branch 1 and 2) has also a similar CDF to the Rayleigh distribution but shifted to the left because its radiation efficiency is lower. The horizontal spacing between the measured antenna (e.g. branch 1) and the reference antenna is equal to the radiation efficiency. The difference between the selection combined CDF and one of the branches CDF at a specific level, typically at 1%, is the diversity gain. If the difference is between the reference antenna CDF and the selection combining CDF, then it is called effective diversity gain, which is the "real" improvement from the individual ideal antenna.

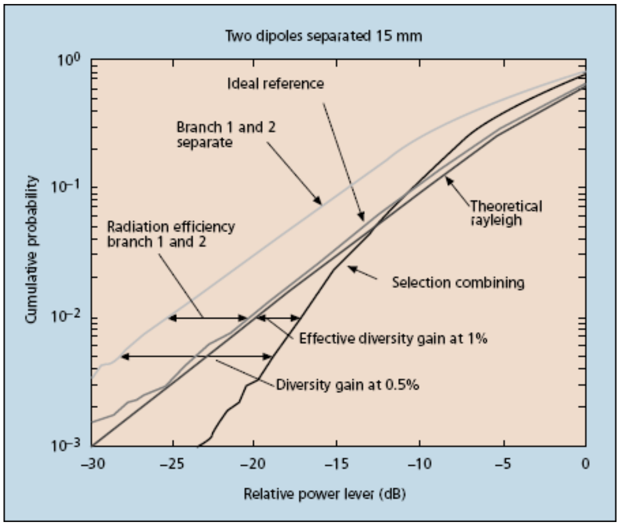


Figure 1. Example of cumulative probability distribution function of the measured signal powers [1]

The MIMO capacity can be calculated from the measured normalized S_{21} values between the 3 wall antennas of the reverberation chamber and the antennas under test (n), in a 3 x n MIMO configuration [1]. The capacity **C** in this case is given as:

$$\mathbf{C} = \log_2(\det(\mathbf{I}_M + (SNR/3)\mathbf{H}\mathbf{H}^*)) \qquad (1)$$

where **H** is the 3 x n element channel matrix. Since **H** consists of measured values it includes effects from coupling and antenna radiation efficiency.

III. WLAN PRESTTA ANTENNA

Ethertronics' WLAN Prestta antenna provides a standard solution for wireless LAN applications, obtaining excellent performance in a reduced volume. It is designed using Ethertronics' patented IMD (Isolated Magnetic Dipole™) technology which optimizes isolation and allows size reduction.

The main advantages of this antenna are that it can be embedded inside devices, removing all external antennas and reducing device size, and that it can be implemented and surface mounted directly on the PCB, avoiding in this case long lossy cables, while maintaining/improving the antenna performance. In addition, since it is a standard product, it will result in a lower-cost antenna solution.

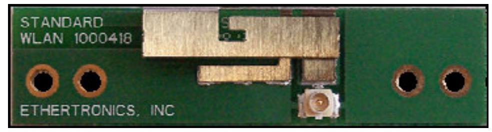


Figure 2. WLAN Prestta Antenna

The antenna performance in free space when implemented on the standard 45 x 11.3 x 0.8 mm PCB, as shown in Figure 2, has a radiation efficiency average of 65% and reaching 70% in the highest bands, with VSWR less than 2:1.

For more details about the Ethertronics' WLAN Prestta antenna, see WLAN Prestta datasheet [2] at Ethertronics' webpage www.ethertronics.com.

IV. EMBEDDED PRESTTA ANTENNAS VS. EXTERNAL DIPOLES

Gateways, access points and routers are commonly implemented with external sleeve dipole antennas. The number of antennas is increasing as the new standard 802.11n is MIMO based and it is common nowadays to see three or four antennas in the same device, which makes antenna performance challenging due to size.

In this section we compare the performance of typical external dipoles with Ethertronics' WLAN Prestta antennas. To do this, we replaced the external dipoles (Figure 3, left side), of a commercially available gateway, with Prestta antennas (Figure 3, right side) separated the maximum distance in order to enhance the ability of receiving uncorrelated signals and maximize the diversity gain. The original sleeve dipoles were still present, stowed and with the cables fixated apart, when the Prestta antennas were evaluated.

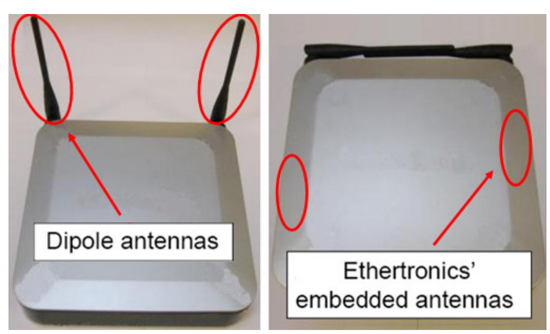
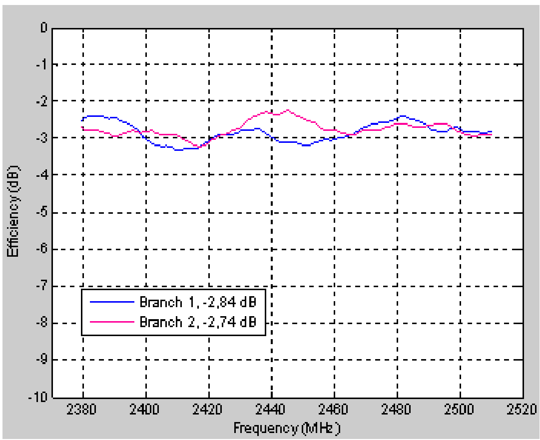
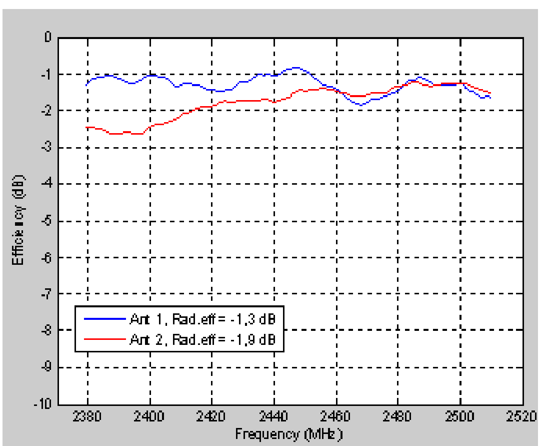


Figure 3. External dipoles on gateway (left). WLAN Prestta antennas embedded on gateway (right)

Figure 4 shows the radiation efficiency of the dipoles (a) and Prestta antennas (b). The former has an average efficiency of about -3dB on both antennas and the latter has an average of -1.33 dB for antenna 1 (left antenna in Figure 3) and -1.92 dB for antenna 2 (right antenna in Figure 3). Therefore, Ethertronics' Prestta antennas provide more than 1 dB improvement in efficiency.



a) Sleeve dipoles



b) Prestta antennas

Figure 4. Radiation efficiency

The gain performance requirement for this particular device was to achieve a minimum of 2 dBi gain of the combined radiation pattern in 3 separate orthogonal cuts. The original dipole antennas do not reach 2 dBi gain in any angle in any polarization for frequencies below 2.46 GHz, and just above at a few angles over 2.46 GHz. Ethertronics' WLAN Prestta antennas have around 3.3 – 3.6 dBi gain on average for both antennas. The radiation patterns are somewhat disturbed by the ground plane and merged constructively resulting in high gain. This will enhance the radiation pattern isolation between antennas and result in higher diversity gain.

Diversity measurements were carried out in a reverberation chamber. The original antennas have a correlation factor of 0.0249 while Ethertronics' Prestta antennas have a correlation factor of 0.0245. In terms of diversity gain, the original antennas have 7.28 dB diversity gain, while the Prestta antennas have 8.16 dB, providing approximately 1 dB of diversity gain improvement.

To summarize, Ethertronics' Prestta antennas show higher performance avoiding the unnecessary long lossy cables, and considerably reducing the total volume occupied with the advantage of being embedded inside the device.

Let us focus now on the throughput data comparison between sleeve dipoles and WLAN Prestta antennas. The antennas evaluated were implemented in an AP (Access Point). The station we used to compute the throughput was a USB dongle supporting 802.11n, which holds MIMO technology. After it was connected to a PC, the measurement was established uplink, from AP to station. The channel measured was Ch6 (HT 40 MHz) at 2.4 GHz. The average data rate was measured from the transmitting data.

The initial AP contained 3 sleeve dipoles which were subsequently replaced by 3 embedded Prestta antennas, as shown in Figure 5. The embedded solution has a significantly smaller dimension compared with the dipole antennas and in addition they can be shielded inside the AP housing.

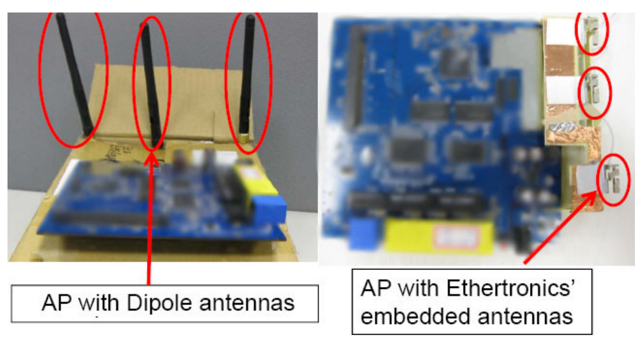


Figure 5. External dipoles on AP (left). WLAN Prestta Antennas embedded on AP (right)

By comparing the return loss (RL) of both types of antennas in Figure 6, the Prestta antennas have equivalent return loss bandwidth required as the dipoles in both frequency bands, at 2.4 GHz and 5 GHz. As the WLAN Prestta antenna is a standard product, the frequency tuning can be done by changing the ground around the antennas if needed for specific installations. Additionally, the Prestta antennas in Figure 6 provide better out of band rejection, which is another potential performance and cost benefit.

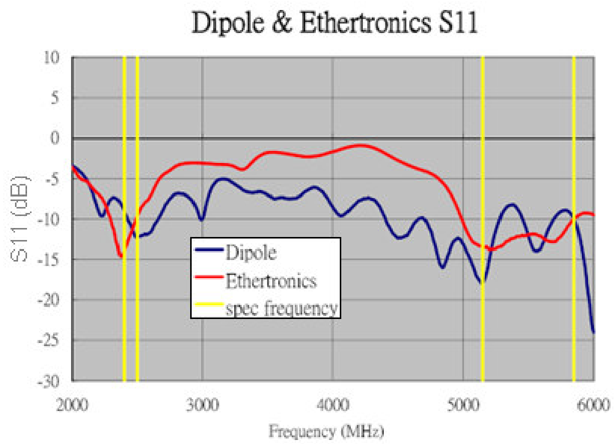


Figure 6. Dipole vs. Prestta antennas RL measurement

The throughput measurement was performed in a basement where the noise at 2.4 GHz was minimized. The test was carried out in 3 different environments characterized as follows in Table I.

TABLE I
TEST ENVIRONMENT

Site 1	Station 30 cm from AP
Site 2	Station 1 m from AP, through a concrete wall
Site 3	Station 7 m from AP, through a concrete wall

In Site 1, where the distance is 30 cm between the AP and the station, both antennas achieved maximum data rate of >74 Mbps. When the station was tested at Site 2 or Site 3, i.e. 1 m or 7 m from the AP respectively and through a concrete wall, the data rate decreased due to the distance and concrete wall, as shown in Figure 7.

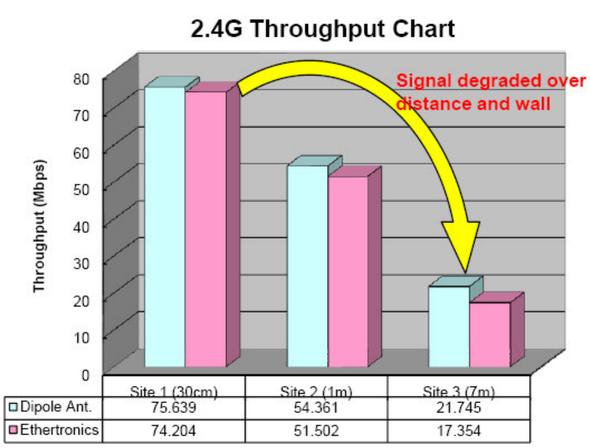


Figure 7. Throughput results on 2.4 GHz band

By analyzing the differences in data rates for the two further locations of the station, we can conclude that both antennas have similar degradation over distance and the throughput data rates are very similar. At Site 2, dipoles antennas obtained 28.13% degradation, while the Prestta antennas obtained 30.59%. At Site 3, the dipoles throughput degradation was 71.25%, in contrast to 76.61% of the Prestta antennas. At Site 3, where the antennas have larger difference in the throughput degradation from Site 1, the discrepancy is only 5%.

Through those two analyses we have demonstrated that Ethertronics' WLAN Prestta antenna has an excellent performance when embedded in gateways removing the large external dipoles from the design.

V. EMBEDDED PRESTTA ANTENNAS VS. OTHER VENDOR'S EMBEDDED ANTENNAS

The trend today is to embed the antennas in the devices for shrinking the size and for better appearance of the products. We compare now our WLAN Prestta antenna with other vendor's antenna, obtained from a commercially available AP. Ethertronics' WLAN Prestta antenna is 50% smaller in height and also 50% smaller in length, as can be seen in Figure 8.

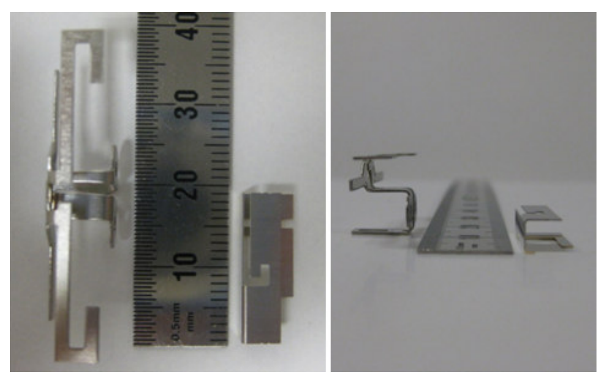
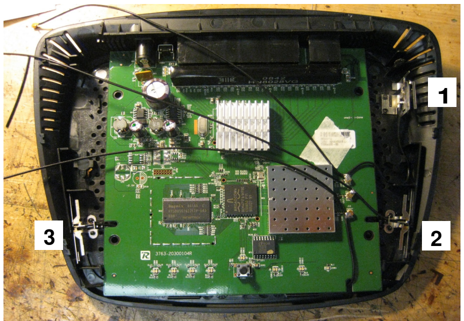


Figure 8. Size comparison of other vendor's antenna and Prestta antenna: top view (left) and side view (right)

The AP evaluated was 802.11n enabled and contained 3 embedded antennas, as shown Figure 9a. The WLAN Prestta antennas, in Figure 9b, were implemented on the real board assembled on the original housing. The Prestta antennas were placed in the same location as the original ones and they use the same cables. Note that the overall housing size (width and height) could be drastically reduced if the Prestta antennas are directly implemented on the main board.



a) Original embedded antennas (referred as Baseline)

b) WLAN Prestta antennas on the real board

Figure 9. AP market product

Ethertronics' patented IMD technology is characterized for improving the isolation. Figure 10 shows the isolation measured between antennas #1 and #2, which are the neighboring antennas placed closest. Although the Prestta antennas are mounted on the same board, and therefore there would be more possibility of surface currents to increase the coupling, they have approximately 5 dB higher isolation compared to the original embedded antennas.

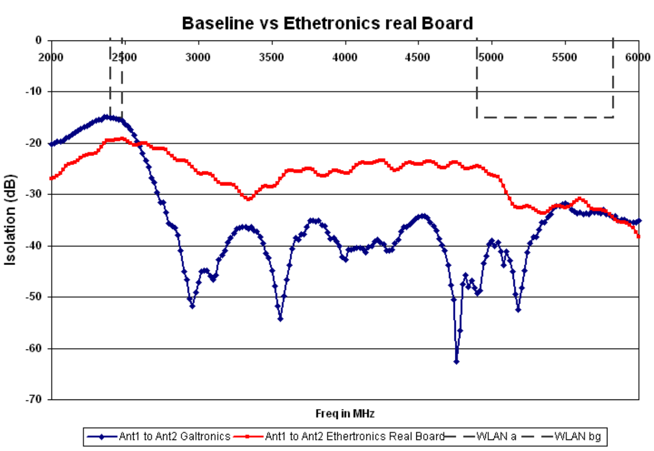
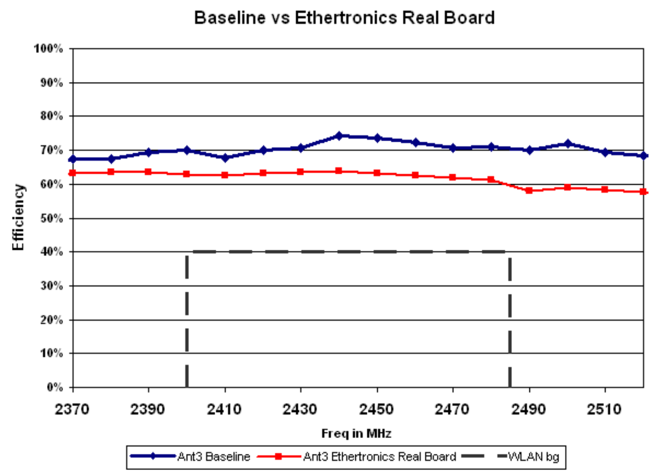
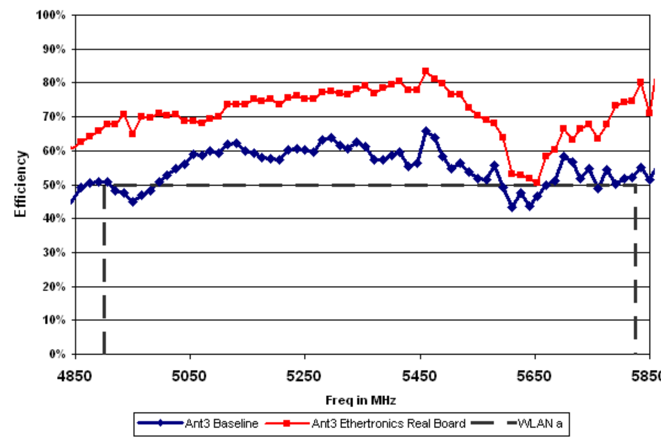


Figure 10. Isolation Baseline vs. Ethertronics Real Board

Figure 11 shows the radiation efficiency for the antennas. For the frequency band 802.11bg the radiation efficiency of the Prestta antenna is 60% average in the whole frequency band, distant from the minimum efficiency required, as shown in Figure 11a. In Figure 11b, it can be observed that the performance of the Prestta antenna is also well above the minimum specification and is superior to the original antenna.



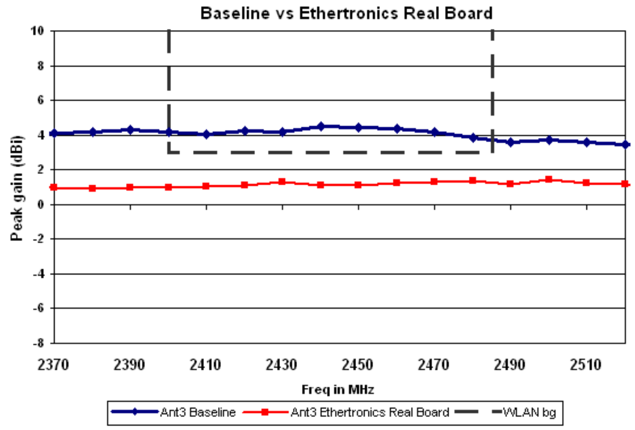
a) WLAN bg



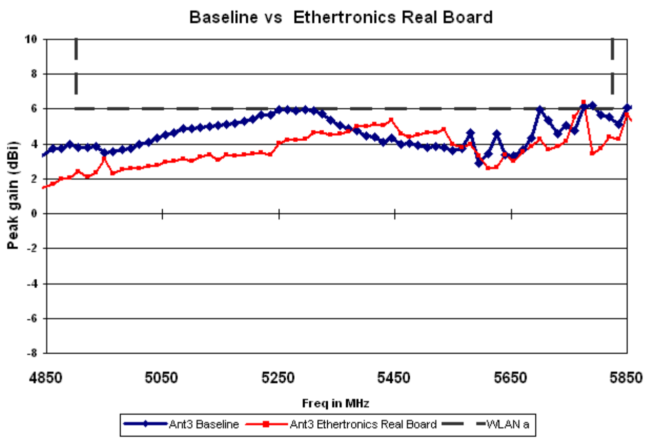
b) WLAN a

Figure 11. Radiation efficiency of Baseline vs. Ethertronics Real Board

Figure 12 illustrates the peak gain for each type of antenna. In the 802.11bg frequency band, shown in Figure 12a, the WLAN Prestta antenna fulfills the maximum peak gain requirements from the FCC (Federal Communications Commission), while the original antenna exceeds the maximum. Both antennas accomplish the maximum peak gain requirements in the 802.11a frequency band, as can be seen in Figure 12b, even though the Prestta antenna has higher efficiency, as shown in Figure 11b.



a) WLAN bg



b) WLAN a

Figure 12. Peak gain Baseline vs. Ethertronics Real Board

We can conclude that the overall performance of Ethertronics' WLAN Prestta antennas is comparable or even better than the performance of the original embedded antennas, with half the volume size. Therefore, by using Ethertronics' WLAN Prestta antennas, the size of the device could be significantly reduced while maintaining the performance. In addition, the Prestta antenna solution would be lower cost since less material (metal) is used, and as the antennas could be surface mounted directly on the main board, we could also reduce the cost of manufacturing, avoiding heatstaking and long cables.

VI. PERFORMANCE OF PRESTTA ANTENNAS EMBEDDED IN A GATEWAY

This last section presents a typical Ethertronics' WLAN Prestta antenna solution implementation. The device is a gateway supporting the standard 802.11n and has 3 WLAN Prestta antennas.

The 3 antennas are implemented directly on the board of the device, placed each in a different polarization and fed by transmission lines. The largest distance between antennas is only 35 mm. Figure 13 shows only portion of the layout drawing due to confidentiality reasons.

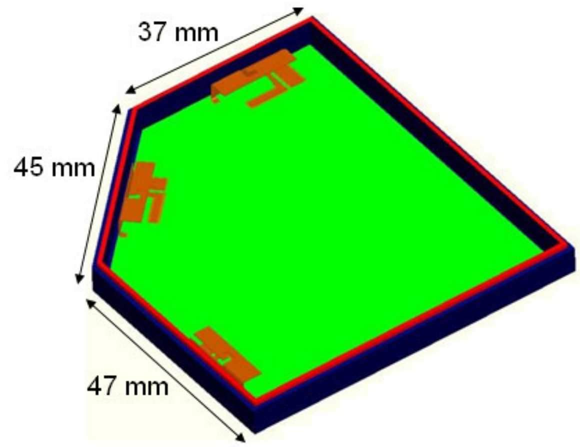


Figure 13. Gateway board design with 3 Prestta antennas

Since the IMD technology allows the antennas to be more independent from the large board and it is only influenced by the very near ground surroundings, the WLAN Prestta antenna can be easily tuned by changing the ground layout around the antenna to compensate for the small frequency shifts that might occur when placed in different products. The ground modification also helps the isolation between antennas.

Figure 14 shows the isolation between adjacent Prestta antennas. We can appreciate how the minimum isolation is adjusted to be outside the frequency bands of interest, due to the combination of IMD technology and ground modification.

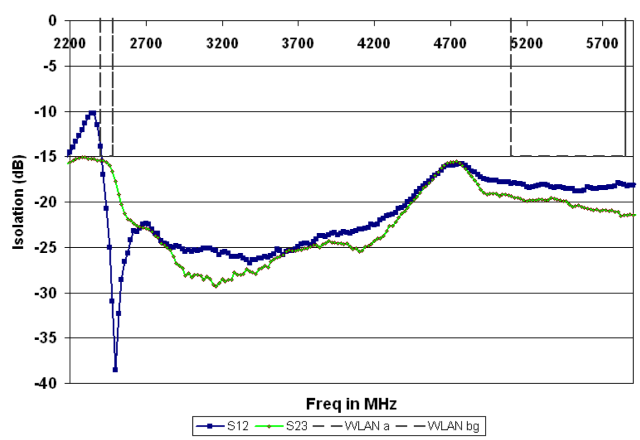
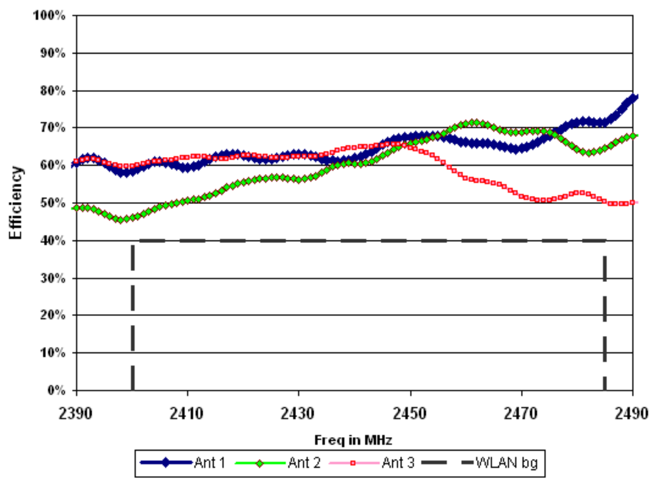
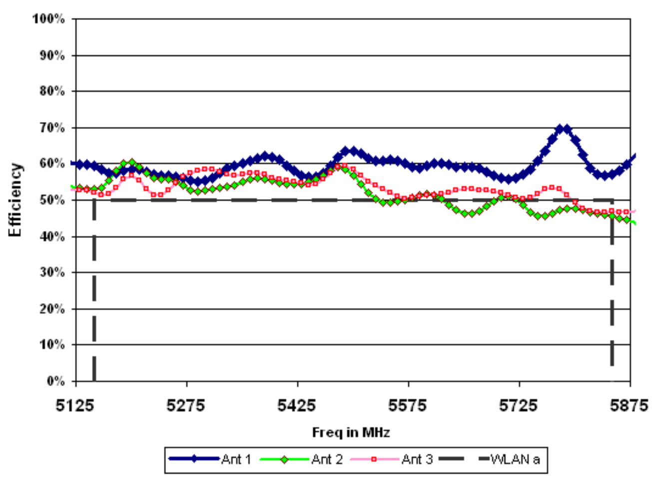


Figure 14. Isolation between adjacent Prestta antennas

The WLAN Prestta antennas exceed roughly 50% radiation efficiency in all frequency bands, as can be observed in Figure 15, which is an excellent value if we consider the small antenna size and the limited available space for the antennas.



a) WLAN bg

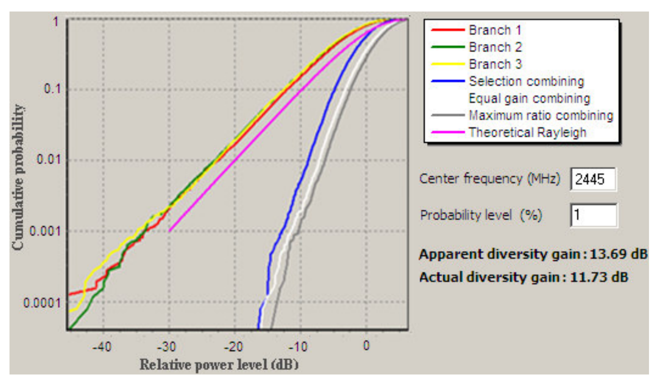


b) WLAN a

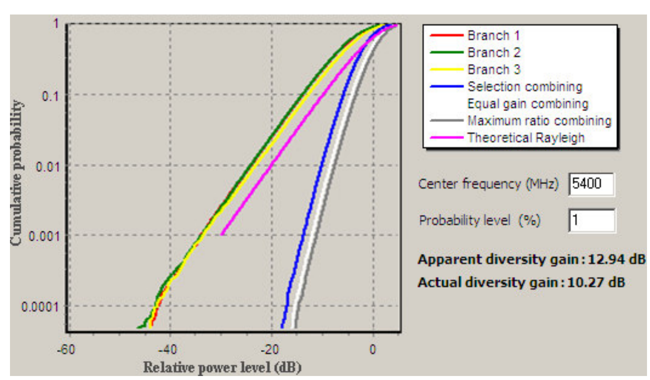
Figure 15. Radiation efficiency of WLAN Prestta antennas

The following curves in Figure 16 show the cumulative probability distribution function (CDF) of the WLAN Prestta antennas measured in a reverberation chamber, from where the diversity gain can be calculated. Branch 1 corresponds to the CDF of Ant 1, branch 2 to the CDF of Ant 2 and so on. The Theoretical Rayleigh distribution is, as explained in section II, the theoretical simulation of a multipath environment. The 3 different branches have very similar slope to the theoretical Rayleigh distribution, so it is assured to be a scattering environment. The reason why the branches are shifted to the left compared to the Rayleigh distribution is because the theoretical curve would be ideal performance and the 3 antennas have lower radiation efficiency.

In Figure 16 there are also 3 more CDFs corresponding to three different MIMO techniques: selection combining, equal gain combining and maximum ratio combining. The diversity gain results in Figure 16 correspond to the selection combining technique. The apparent diversity gain at 1 percent CDF level is 13.69 dB at 2445 MHz and 12.94 dB at 5400 MHz. The actual diversity gain, which is the "real" improvement in comparison to the individual ideal antenna, is 11.73 dB and 10.27 dB for 2445 MHz and 5400 MHz respectively. This means that if we use the 3 Prestta antenna system instead of a very good single antenna on a system that allows a fading margin of 20 dB in order to receive with sufficient quality 99 percent of the time (i.e. 1 percent CDF level), we can reduce the fading margin by about 10 dB.



a) 2445 MHz



b) 5400 MHz

Figure 16. Diversity gain of WLAN Prestta antennas

Table II shows the correlation values between pairs of antennas. At 2445 MHz the correlation coefficients are below 0.13 and at 5400 MHz they are lower than 0.085, which are very low values. As expected, the correlation coefficients at 5400 MHz are lower than at 2445 MHz since the distance between antennas in wavelengths is larger at 5 GHz. We can compare these results with [3], where correlation values are calculated for two parallel (half-wave) dipoles horizontally separated with a variable distance *d*. As mentioned previously, the largest distance between the Prestta antennas is 35 mm (0.28λ at 2445 MHz), so if we compare to the dipoles, the higher correlation values are within a difference of about 0.05.

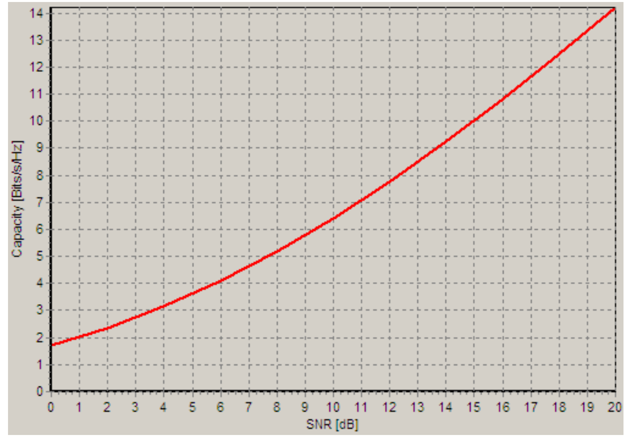
TABLE II
CORRELATION COEFFICIENTS

Between antennas	2445 MHz	5400 MHz
1-2	0.1281	0.0833
2-3	0.0012	0.0225
1-3	0.1243	0.0312

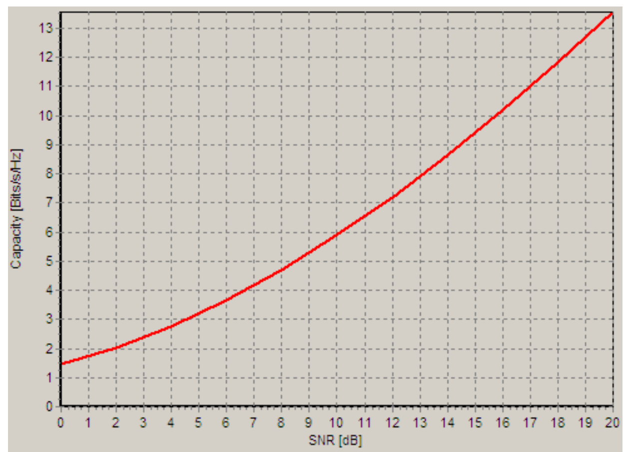
The MIMO capacity can be measured from the measured normalized S_{21} values between every of the 3 wall antennas of the reverberation chamber and the 3 WLAN Prestta antennas, in a 3 x 3 MIMO configuration. Table III shows the measured capacity values at 2445 MHz and 5400 MHz. For a SNR (Signal to Noise Ratio) of 20 dB the capacity is 14.2 and 13.6 Bits/s/Hz for 2445 and 5400 MHz, respectively. We refer to [4] in order to compare the capacity results with a 3x3 MIMO system of half-wave dipoles at 1800 MHz. At the same SNR of 20 dB and a distance of 0.25λ, the measured MIMO capacity is in a range between 13 and 15 Bits/s/Hz for different scenarios. Therefore the WLAN Prestta antenna solution capacity results present a good MIMO performance.

TABLE III
MIMO CAPACITY VALUES

SNR (dB)	Capacity (Bits/s/Hz)	
	2445 MHz	**5400 MHz**
0	1.72	1.46
2	2.36	2.03
4	3.15	2.76
6	4.10	3.65
8	5.19	4.69
10	6.42	5.88
12	7.77	7.20
14	9.24	8.64
16	10.8	10.2
18	12.5	11.8
20	14.2	13.6



a) 2445 MHz



b) 5400 MHz

Figure 17. Capacity of a 3x3 MIMO system with receiving WLAN Prestta antennas

We have proved that Ethertronics' standard WLAN Prestta antenna can be a low-cost solution to implement in MIMO systems, providing good performance and an embedded antenna solution using small volume.

VII. CONCLUSION

This paper presents Ethertronics' WLAN Prestta™ antenna as a low-cost solution for MIMO technologies in gateways, routers or access points. This antenna is designed using Ethertronics' patented IMD (Isolated Magnetic Dipole™) technology.

We have presented several comparisons of the WLAN Prestta™ antenna with other external and embedded antennas, concluding that our solution performs same or even better than other vendors' solution and uses a considerably smaller volume. In addition, a typical implementation of a WLAN Prestta™ antenna MIMO solution is presented, obtaining good performance in a reduced area.

To summarize the advantages of the Prestta™ antenna, and consequently the IMD technology, they are:

- ✓ **High Efficiency.** Excellent antenna performance for its small size.
- ✓ **Pick and Place/SMT.** Lower cost for manufacturing.
- ✓ **High Isolation.** PCB layout flexibility and possibility of components co-location.
- ✓ **Resistance to detuning.** Placement and form factor flexibility.
- ✓ **No Cables/Heatstaking.** Lower cost in material and manufacturability, plus performance enhance by avoiding long lossy cables.
- ✓ **Smaller Footprint.** Lower antenna cost and flexibility to reduce the volume of the devices.

Ethertronics' WLAN Prestta™ antenna is the perfect candidate to implement a MIMO antenna solution in gateways, access points and routers for its performance, cost and flexibility.

REFERENCES

[1] P-S. Kildal, Kent Rosengren, "Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency and diversity gain of their antennas: simulations and measurements in reverberation chamber". IEEE Communications Magazine, pp. 104-114, Vol. 42, No. 12, Dec. 2004.

[2] Ethertronics' website, WLAN Prestta™ antenna datasheet. www.ethertronics.com/file_library/File/datasheets/3-Prestta_WLAN_1000418.pdf

[3] A. Khaleghi, "Diversity techniques with parallel dipole antennas: Radiation pattern analysis". Progress in Electromagnetics Research, PIER 64, 23 – 42, 2006.

[4] Valenzuela-Valdes, J.F.; Martinez-Gonzalez, A.M.; Sanchez-Hernandez, D.A, "Diversity Gain and MIMO Capacity for Nonisotropic Environments Using a Reverberation Chamber", Antennas and Wireless Propagation Letters, IEEE. Volume 8, 2009 Page(s):112 - 115

Carmen Redondo joined Ethertronics in January 2008, where she worked in several design centers in Europe, US and China. Previously she worked for Flextronics, in the antenna department, for one year. Ms. Redondo gained in 2006 the Telecommunication Engineering degree from Universidad Europea de Madrid, in Spain, and the MSc. in Hardware for Wireless Communication from Chalmers University of Technology in 2007, in Sweden. She made her master thesis about conformal antennas for avionics applications at DLR (German Aerospace Center), in Germany, where she patented a new conformal antenna.

About Ethertronics, Inc.

Ethertronics designs and manufactures high-performance embedded antenna solutions for wideband and multi-band wireless devices. Ethertronics' leading-edge product lines, including Prestta™ stamped metal, Savvi™ ceramic, and Tavvel™ active antennas support a wide range of applications including cellular, UMTS, WiFi, WiMAX, Bluetooth, GPS, FM, MediaFLO and DVB-H/T, among others. The company's patented Isolated Magnetic Dipole™ (IMD) technology enables smaller size, design implementation flexibility, shortened design cycle and higher overall performance, while simultaneously meeting and improving upon standard safety emission requirements. Ethertronics' antennas have been selected by major customers worldwide garnering an installed base of more than 200 million units. Ethertronics maintains a global network of design centers and low-cost, high-volume manufacturing operations. For more information, visit www.ethertronics.com.